Soil property patterns and topographic parameters associated with ephemeral gully erosion

R.D. Lentz, R.H. Dowdy, and R.H. Rust

ABSTRACT: The pattern of ephemeral gully erosion and associated soil properties were investigated in three southeastern Minnesota soilscapes during 1988 and 1989. The associations between topographic attributes and erosion characteristics of sample sites were also examined. No ephemeral erosion was measured after the investigation began in the drought year of 1988. In 1989 soil lost from ephemeral gullies ranged from 0.8 to 1.6 Mg/ha (.4 to .7 ton/ac) at the study sites, or one-tenth of that reported in the literature for similar watersheds. Pre-1988 data available at one site showed that soil voidage was an order of magnitude greater during the wetter-than-normal 1986 season. A simple erosion model predicting topsoil removal and subsoil mixing in upper reaches and deposition in lower ephemeral gully reaches, does not accurately describe erosion processes in these landscapes. Impact of ephemeral erosion on soil properties in landscapes varied depending on relative 1) rill and interrill contributions, 2) proclivity for channel drifting, and 3) occurrence of depositional sorting in channels. Topographically sensitive controls of ephemeral erosion, such as surface saturation and stream transport capacity, played different roles in channel formation at each site. Topographic indices most useful for predicting ephemeral erosion were planform curvature, profile curvature•slope, Ln (unit area/slope), unit area•slope, and planform curvature•upstream contributing area•slope.

Soil conservationists began systematic study of ephemeral gully erosion only in the last decade *(5)*. Ephemeral gullies are scoured by concentrated flow, but unlike rills, ephemeral channels are believed to recur in the same location each season and are strongly controlled by landscape configuration. Ephemeral gullies are larger than rills but are smaller than gullies, i.e., small enough to allow passage of tillage implements. Ephemeral channels tend to form in swales or depressions in the upper reaches of a drainage network *(6)*. To date, relatively few studies have attempted to quantify ephemeral erosion or describe patterns of gully formation *(18)*. Present data suggest that sediment production from ephemeral erosion may range from 14 to 147 percent of that produced by interrill and rill erosion *(7)*. Repeated cycles of ephemeral channel formation and tillage filling remove a greater volume of topsoil from these areas and can quickly reduce crop yields *(1)*.

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The importance of employing overall landscape analysis to assess hydrology, soil erosion, soil property, and crop productivity conditions has been emphasized in the literature *(10)*. Ultimately, landscape analysis permits examination of spatially dependent characteristics and processes, and develops causal or predictive relationships that are universally applicable in diverse environments. To achieve this goal, researchers require a nonpositional method of relating spatial properties within landscapes. In other words, the location in a landscape associated with certain characteristics of interest is not defined in terms of fixed coordinates but by parameters that describe process potentials inherent at the location. Soil map unit components are considered nonpositional and have been employed to make inferences concerning characteristics and processes at given locations. However, map unit components do not provide enough specific information on shape of land surface, which influences hydrologic processes. Because landscape processes are very sensitive to landscape configuration, para-

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meters have been derived from topographic attributes.

Parameters such as topographic position, aspect, slope, surface curvature parallel (profile), and perpendicular (planform) to direction of maximum slope, length of contributing slope (upstream distance), and a parameter related to unit area (A), defined as upstream contributing area divided by unit contour length, have been related to soil properties in landscapes *(4, 12, 15)*. Unit contour length is defined as the size of land surface unit that forms the basis of calculated hydrologic parameters *(10)*. Indices listed above also are related to soil water content *(8)*. An additional composite parameter, unit area divided by slope (As), has been shown to successfully describe differences in soil water content across the landscape *(2, 11)*. Thorne et. al. *(19)* employed a composite topographic index (CTI), the product of upstream contributing area, slope, and planform curvature, as an index of the erosive power of concentrated flow to predict where ephemeral gullies occur in the landscape. Two composite parameters were employed by Moore *(11)* for the same purpose. At lower positions in the catchment, ephemeral gully locations were best predicted from the composite parameter (unit area•slope) or ABS; whereas at upper catchment positions, location of gullies were predicted by log of As (LNAS).

The objectives of this research were three-fold: 1) identify the pattern of ephemeral erosion and measure channel voidage occurring across small watersheds in three contrasting soilscapes of southeast Minnesota; 2) determine how soil properties are related to topographic parameters and examine the relationship between either soil properties or topographic parameters with ephemeral gully erosion; and 3) test the following hypothesis—ephemeral gully erosion may be modeled simply as a process in which topsoil is removed from an area immediately adjacent to recurrent channels and deposited at low lying positions. We will refer to this hypothesis as the conventional ephemeral erosion model.

Study area and methods

Mean annual precipitation in the region studied is about 735 mm (29 in); 67 percent falls during the growing season from May to September. Thunderstorms occur on about 45 days during the warm months from April to September. Soil frost develops around December 1 and thaws in mid-April. Precipitation has fluctuated wildly over the last decade. September 1986 marked the abrupt end of one of the wettest decades on record. Subsequent years were droughty. Southeastern Minnesota warm-season precipitation was 80-90 percent of normal in 1987, 50-75 percent of normal in 1988, and 75 percent of normal in 1989 *(20)*.

Study sites were subject to severe ephemeral erosion and were representative of regional soil and cropping patterns (corn and soybeans). Minimal conservation practices were employed. Tillage practices included conventional clean tillage across slope to prepare seedbed and plant, a single mid-season cultivation to control weeds, and fall chisel or disking with 5-25 percent crop residue remaining.

Sites were named for the county in which they were located. Figure 1 describes soils at the study sites. The Olmsted site was located about 7 km (4 mi) north of Rochester (SE 1/4, NE 1/4, SE 1/4, Sec. 10, T. 107 N., R. 14 W.). Its watershed encompasses an area of 1.8 ha (4.4 ac), has a vertical relief of about 18.5 m (60 ft), a mean slope of 8.6 percent, and a predominant south-southwest aspect. Soils formed in a mantle of loess that ranges from one to more than two meters in thickness. Port Byron silt loam, 1-5 percent slopes (fine-silty, mixed, mesic Typic Hapludolls) occurs on summit and backslope positions; Lindstrom silt loam, 6-16 percent slopes (fine-silty, mixed, mesic Cumulic Hapludolls) occurs on footslope and toeslopes.

The Rice site was located approximately 66 km (40 mi) south of Minneapolis (NE 1/4, SE 1/4, SE 1/4, Sec. 26, T. 111 N., R. 22 W.) on a 2.4 ha (6 ac) watershed with a mean slope of 6.1 percent and a westward aspect. Vertical relief is about 14 m (46 ft). This watershed lies in a glacial wastage landscape that is characterized by a complex topography and deranged drainage pattern. Lerdal silty clay loam, 2-6 percent slopes, and 6-12 percent slopes, eroded (fine, montmorillonitic, mesic Udollic Ochraqualfs) occur on backslopes and Lura silty clay loam (fine, montmorillonitic, mesic Cumulic Haplaquolls) occupies footslope and toeslope positions.

The Mower site lies about 24 km (15 mi) southwest of Rochester (NE 1/4, SE 1/4, SE 1/4, Sec. 15, T. 104 N., R. 15 W.). Mower is a 3.15 ha (8 ac) watershed with a mean slope of 3.4 percent, a southerly aspect, and a vertical relief of about 19 m (62 ft). Soils developed in firm glacial till overlain by a thin mantle of loess from 0.09 to 0.5 m (.3-1.5 ft) thick. Tripoli silty clay loam (fine-loamy, mixed, mesic Typic Haplaquolls) occurs on summits and backslopes while Readlyn silt loam (fine-loamy, mixed, mesic Aquic Hapudolls) occupies swales and footslopes.

Air temperature, humidity, wind speed and direction, and rainfall were measured at Rice. Recording rain gauges were installed at Mower and Olmsted, and field measurements were begun in late May 1988. During the summer of the 1988 drought, rainstorms were not sufficiently intense or persistent to produce ephemeral erosion. During 1989, ephemeral gullies developed at each site during early spring before fields were planted, and again at Mower and Olmsted in late summer. Figure 2 presents rainfall data associated with ephemeral erosion events at each site.

Table 1. Estimated soil voidage from ephemeral gullies at study sites.

Site	Date	Crop	Cover*	Event Rainfall	Rainfall Duration	Soil‡ Voidage
			%	mm	hours	Mg ha^{-1}
Olmsted	4/3/89	Corn	15r	15	7.5	0.5
Olmsted	8/4/89	Corn	100c	49	2	1.0
Rice	4/1/89	Soybeans	7r	7	2	2.1
Mower†	5/13/86	Soybeans	25r	53	24	6.9
Mower†	7/5/86	Soybeans	25c	25	6	2.4
Mower†	7/26/86	Soybeans	80c	53	16	0.5
Mower†	7/8/87	Soybeans	35c	48	7	5.5
Mower	4/3/89	Soybeans	15r	15	7	0.2
Mower	7/11/89	Soybeans	80c	35	4.5	0.6

* Surface cover given for crop (c) or residue (r).
† Unpublished data of USDA SCS
‡ Bulk density (Mg m^{-3}) Olmsted 1.15; Rice 1.23; Mower 1.22

Topographic analysis. Watershed topography was characterized using a Geodimeter Model 136 **(1)** survey instrument. The program SPLIN2G *(9)* fit a Laplacian Smoothing spline surface to the irregularly spaced field data, and interpolated elevation values for X and Y coordinates of a uniform 3 x 3 m (10 x 10 ft) grid. The resulting digital elevation models (DEM) described the surface configuration of each watershed. Elevation error associated with DEMs was estimated to be ±0.025 m (.08 ft).

A FORTRAN program *(14)* analyzed each DEM and estimated five principal topographic indices for surface points corresponding to all nonperipheral grid nodes, including: 1) slope—the maximum rate of change of elevation of the surface (m/m); 2) aspect—the compass bearing of the maximum downward slope (degrees clockwise from north); 3) profile curvature—second derivative of an arc defined by the intersection of the surface with a vertical plane that passes through slope vector and node (m/m^2, positive-convex); 4) planform curvature—second derivative of the arc formed at the surface by a vertical plane perpendicular to slope vector and passing through node (m/m^2, positive-concave); and 5) upslope contributing area—the entire upstream area (m^2) that contributes flow to the surface point corresponding to each node. Topographic parameters described in the introduction are simply combinations or transformations of these basic attributes. Finally, we included a parameter that described the shortest horizontal distance from the location of interest to a known ephemeral channel position.

Ephemeral erosion. Data on size and pattern of ephemeral gullies that formed at Mower during 1986-88 seasons were provided by the USDA-SCS; measurements were made with a tape. In 1989, measurements at all sites were made in the following manner: Ephemeral gullies were identified as channels in which development and orientation were associated with incipient drainageways. These gullies, which were oriented at angles to furrows, were readily distinguished from rills that formed in, and ran parallel to, tillage marks. Ephemeral gullies that formed were measured before the next tillage operation. Channels and deposition zones were delineated and partitioned into reaches of similar size and configuration. Channel area of each reach was measured at two or three locations using a micro-relief meter for large channels and a photographic technique for small gullies. In the latter method, cross-sectional gully areas were measured from photos taken on-site. Channel voidage was computed by summing the products of channel length and average channel area (for each reach) over all channel sections and reaches comprising the gully. Based on the accuracy of the relief meter and estimated unmeasured channel sinuosity, we estimate a maximum of 15 percent error was associated with these soil voidage measurements.

Soil sampling. At each site, ephemerals were divided into three blocks, including lower channel (depositional), mid-channel, and upper channel. Within each block four "affected" plots were located over the ephemeral channel, if present, or in the swale bottom. The term "affected" refers to field areas directly impacted by erosive or depositional processes of ephemeral gullies. "Nonaffected" plots were randomly located on one side of the channel, at least three meters along the furrow and away from the affected plot. "Nonaffected" areas were considered to be beyond the influence of present ephemeral gullies, but were subject to interrill and rill processes. Each plot consisted of 3 m (10 ft) of crop row. Three of the four pairs of affected/nonaffected plots were randomly selected for sampling in the fall of 1989. A preliminary examination of soil profiles beneath affected areas revealed that significant variability in soil texture occurred at the 0.18-0.35 m (.6-1 ft) depth. In each selected plot, soil samples were taken from two narrowly defined layers (0.05-0.15 m and 0.18-0.35 m) in order to better observe these textural contrasts. Samples consisted of 2.3 cm (1 in) diameter cores, taken at the lowest point in each swale, but to one side of any channel. In addition, a five or six sample transect was made across the mid-channel zone of two different ephemeral gully systems in each landscape. Particle size analysis, total organic carbon, and bulk density were determined for the two layers sampled in each core.

Table 2. Pearson's coefficients for all significant correlations between topographic parameters and field properties.

Topographic Parameter	Correlated Property	Correlations		
		Olmsted	Rice	Mower
Channel cross-sections	Sand (18-35cm)	0.56†	0.36*	-0.42*
	A horizon thickness	0.10	-0.22	-0.53*
	Planform curvature	0.49†	0.56†	0.37‡
Deposition type (extent of deposition present in channel)	Organic carbon (5-15cm)	-0.47†	0.29	0.26
	Bulk density (5-15cm)	0.54†	-0.28	-0.35
	Bulk density (18-35cm)	0.41*	-0.12	-0.61†
	Sand (18-35cm)	0.42*	0.18	0.21
	Clay (18-35cm)	-0.18	-0.44*	-0.27
	A horizon thickness	-0.10	0.38*	0.05
	Slope	-0.60*	-0.42	-0.62†
Distance to channel	Organic carbon (5-15cm)	0.38*	0.09	0.45*
	Clay (5-15cm)	-0.50†	0.05	0.24
	Sand (18-35cm)	-0.47†	-0.28	-0.04
	A horizon thickness	-0.47†	0.21	0.39
	Planform curvature	-0.35‡	-0.72†	0.21
Upstream area	Organic carbon (5-15cm)	0.38*	0.16	0.30
Slope	Organic carbon (5-15cm)	0.04	-0.60†	-0.34
	Sand (5-15cm)	-0.23	0.37*	0.19
	Bulk density (18-35cm)	-0.37*	0.54†	0.69†
	Sand (18-35cm)	-0.47*	0.22	-0.31
	A horizon thickness	0.17	-0.71†	-0.06
Planform curvature	Sand (18-35cm)	0.39*	0.08	-0.38†
CTI§	Organic carbon (5-15cm)	0.38*	-0.12	0.26
(Unit area slope)	Sand (5-15cm)	0.02	-0.46*	-0.12
(Unit area•slope)	Organic carbon (5-15cm)	0.39*	-0.01	0.27

*, †, ‡ Significant at 0.05, 0.01, and 0.075 level, respectively
§ CTI = (Upstream contributing area•slope•planform curvature)

(1) Mention of trade names is for reader convenience only and does not imply endorsement by the USDA-ARS or the University of Minnesota over similar products of companies not mentioned.

Table 3. Soil properties* of plots that are either affected or nonaffected by ephemeral erosion processes. Data are given on the basis of site and channel position.

Channel Position	(1) Lower		(2) Mid		(3) Upper		
Erosion Status	Affected	Non-aff	Affected	Non-aff	Affected	Non-aff	Overall
Site: Olmsted (1)							
OC1 (%)	1.84a§	2.11b	2.07a	2.00a	2.04a	2.04a	2.01A
BD1 (g cm⁻³)	1.31b	1.13a	1.12a	1.06a	1.17a	1.13a	1.12A
BD2 (g cm⁻³)	1.21a	1.15a	1.19a	1.15a	1.08a	1.09a	0.04A
S1 (%)	10.6a	9.0a	9.9a	9.7a	7.6a	10.0a	9.6A
S2 (%)	9.0a	8.4a	10.5b‡	7.4a‡	5.6a	2.8a	7.5A
CL1 (%)	28.9a	23.3a	26.1a	23.9a	28.3a	18.0a	24.5A
CL2 (%)	25.8a	27.1a	25.7a	24.4a	28.4a	28.9a	26.3A
ATHK (cm)	60.2a	74.0a	65.9a	52.7a	80.3a	65.3a	60.9A
Site: Rice (2)							
OC1 (%)	2.7a	2.9a	1.58a	1.55a	1.72a	1.70a	1.85A
BD1 (g cm⁻³)	1.12a	1.15a	1.13a	1.30b	1.32a	1.42a	1.25A
BD2 (g cm⁻³)	1.18a	1.22a	1.32a	1.40a	1.32a	1.22a	1.32AB
S1 (%)	21.3a	23.7a	31.7a	31.3a	29.3a	29.2a	29.1B
S2 (%)	16.7a	31.2a	37.1b	29.2a	25.7a	33.1a	29.5B
CL1 (%)	27.0a	34.4a	34.2a	38.0a	34.1a	33.0a	34.9B
CL2 (%)	32.9a	44.3a	37.8a	45.4a	46.0a	41.3a	42.3B
ATHK (cm)	60.0a	60.0a	24.8a	20.5a	20.3a	24.8a	29.8B
Site: Mower (3)							
OC1 (%)	3.96a	4.44b	2.29a‡	3.15b‡	3.17a	3.49a	3.26B
BD1 (g cm⁻³)	1.03a	0.97a	1.30a	1.18a	1.13a	1.12a	1.15A
BD2 (g cm⁻³)	1.11a	1.06a	1.36a	1.29a	1.38a	1.34a	1.27B
S1 (%)	23.9a	22.9a	25.8b	19.0a	26.3a	28.5a	23.0B
S2 (%)	17.7a	11.7a	10.6a	15.7a	5.3a	11.2b	1.3A
CL1 (%)	33.5a	37.0a	28.3a	30.9a	30.6b‡	27.0a‡	30.9AB
CL2 (%)	36.6a	33.3a	29.9a	32.4a	34.5a	36.1a	33.1B
ATHK (cm)	42.3b	32.7a	21.1a	36.3b	29.5a	36.5a	33.3B

* ATHK = A horizon thickness; OC = total organic carbon; BD = bulk density; S = sand; CL = clay; 1 = 0.05-0.15m sampling depth; 2 = 0.18-0.35m sampling depth

† Dissimilar uppercase letters indicate significant differences (P = 0.05) between sites for a given soil property

‡ Affected and non-affected values are different at P = 0.075 significant level

§ Dissimilar lower case letters indicate significant differences (P = 0.05) between affected and non-affected values at each channel position

Regression models. A stepwise regression analysis *(16)* was employed to determine how topographic characteristics (independent variables) at a given location influenced local occurrence or severity of ephemeral channel development (dependent variable). In this statistical analysis, a search algorithm selects the subset of independent variables (i.e., derives a suitably-fitted model) that best explains variation of the independent variable. The model fitted is:

$$C_A = \beta_0 + \beta_1 T_1 + \beta_2 T_2 ... + \beta_n T_n + \varepsilon_i$$

where C_A is a channel formation variable and T_1 are topographic characteristics selected in the analysis.

Results and discussion

Ephemeral erosion. A section of ephemeral gully was composed of a single channel or from two to four parallel channels. Cross-sectional area of a channel ranged from 0.0016 to 0.032 m² (.02-.3 ft²). Ephemeral gully voidage estimates measured in 1989 at each of the watersheds are presented in Table 1. Soil loss to ephemeral erosion on these watersheds was much less than that reported by Spomer and Hjelmfelt *(17)* in Iowa, for a 28 ha (69 ac) loess watershed with 4-12 percent slopes [6.8 Mg/ha (3 ton/ac) in 1984, 17 Mg/ha (8 ton/ac)] in 1985; by Grissinger and Murphey *(7)* in northern Mississippi, for 1.9 ha (5 ac) loess watershed with 0-6 percent slopes [14.7 Mg/ha (7 ton/ac) in 1985] ; and by Thomas and Welch *(18)* in Georgia, for 1.2 (3 ac) and 0.8 ha (2 ac) watersheds with clayey residual soils and 2-8 percent slopes [33.0 Mg/ha (15 ton/ac) average from July 1984 to December 1986]. The disparities are primarily due to a difference in number and intensity of rain storms over watersheds and length of erosion seasons. For example, mean annual rainfall is 1200 mm (47 in) at the Georgia location, 1400 mm (55 in) at the Mississippi location, and 735 mm (29 in) at our sites. Precipitation during the period of observation was 823 mm (32 in) at Georgia and averaged 1071 mm (42 in) per year at Mississippi. This is compared to 330 and 437 mm (13 and 17 in) recorded for the two seasons of our study in southeast Minnesota (1988 and 1989).

Annual soil voidage for Mower (Table 1) in 1986 and 1987 was nearly ten times greater than that observed in 1989. However, comparable events occurred on 7/26/86 and 7/11/89 with respect to intensity and time of season, and resulted in similar soil losses [0.5 and 0.6 Mg/ha (.2 and .26 ton/ac), respectively]. This suggests that although drought reduced ephemeral erosion during 1988 and 1989, relative size and spatial information provided by channel measurements during 1989 were realistic and adequate for analyses of associated topographic relationships.

Soil property-topographic parameter relationships. Pearson's correlation analysis of topographic parameters and soil properties included soil data from sample sites in and adjacent to channels, in addition to five to six samples comprising a cross-section of the mid-channel gully. Correlation analysis was conducted independently for each site (Table 2). In general, correlations with soil properties were not significant across all sites. Most of the significant correlations were site specific, even to the extent that, for a given soil property, correlations were reversed from one site to the next. About 54 percent of significant correlations were observed for the Olmsted location. Stronger soil property/topographic parameter relationships occur at Olmsted because the overall landscape configuration is more extreme, as exemplified by its greater mean slope.

Soil property-channel parameter relationships. The correlation analysis described above also included channel formation parameters. Channel cross-sectional area, a measure of gully erosion severity, was positively correlated to sand content at 0.18-0.35 m (.6-1 ft) depth at Olmsted and Rice sites, but negatively correlated at Mower site (Table 2). The conventional ephemeral erosion model predicts that the surface horizon of eroded soils becomes more similar to that of the subsoil as erosion proceeds. Accordingly, when Olmsted and Rice soils are eroded, sand content should remain constant with depth. Instead, sand content at 0.18-0.35 m depth increases in areas where gully size was larger, suggesting that dilution or diminution of silts and clays occurred in the 0.18-0.35 m layer in affected locations. Increasing sand may be a consequence of preferential removal of silts and clays by concentrated flow. Evidence supporting a dilution process was observed in a soil profile excavated at a mid-channel affected location. Lenses of sand 0.18 to 0.30 m (.59 to .98 ft) thick and 4 to 6 m (13-20 ft) wide were observed in the upper 0.5 m (1.5 ft) of the soil profile. These sand bars probably formed during past ephemeral episodes and were covered by fill from tillage.

It is not clear whether a cause-effect relationship exists between strongly developed ephemeral channels and increasing sand content with depth. Regardless of the cause, this evidence suggests that both degrading and aggrading processes occur at mid-channel positions. This contradicts the conventional ephemeral erosion model (see last paragraphs in Results and Discussion section). The duplicity in process probably is caused by the dynamic nature of individual hydrologic events, or variation between successive events. Channel scouring can occur during event peak flows, but as runoff slows, velocity and transport capacity in stream flows decrease, and sediment is deposited in the scoured channels. The heavier sand fraction dominates deposits of the higher-energy, mid-channel flows. Smaller rainfall events that follow heavy rainstorms yield less runoff, and produce channel flows that terminate before fully traversing the previously incised gullies. Sediment from abbreviated flows is deposited in mid-channel reaches. Such duplicity may produce greater variation among soil properties associated with ephemeral channels and reduce our chances of observing consistent relationships; however, the above example was statistically significant, indicating that some soil property patterns may be generally reflective of ephemeral erosion processes.

The only other soil property significantly correlated with channel area was A horizon thickness at Mower. As channel area increased, thickness of the A horizon decreased, a situation that supports the conventional ephemeral erosion model. Other ephemeral erosion parameters "deposition type"—a measure of extent of deposition occurring in channels and "distance to channel" had significant, though unique, relationships to specific soil properties. Increasing organic carbon at 0.05-0.15 m (.2-.5 ft) depth with distance from channel was significant for both Olmsted and Mower sites and suggests that classical erosion

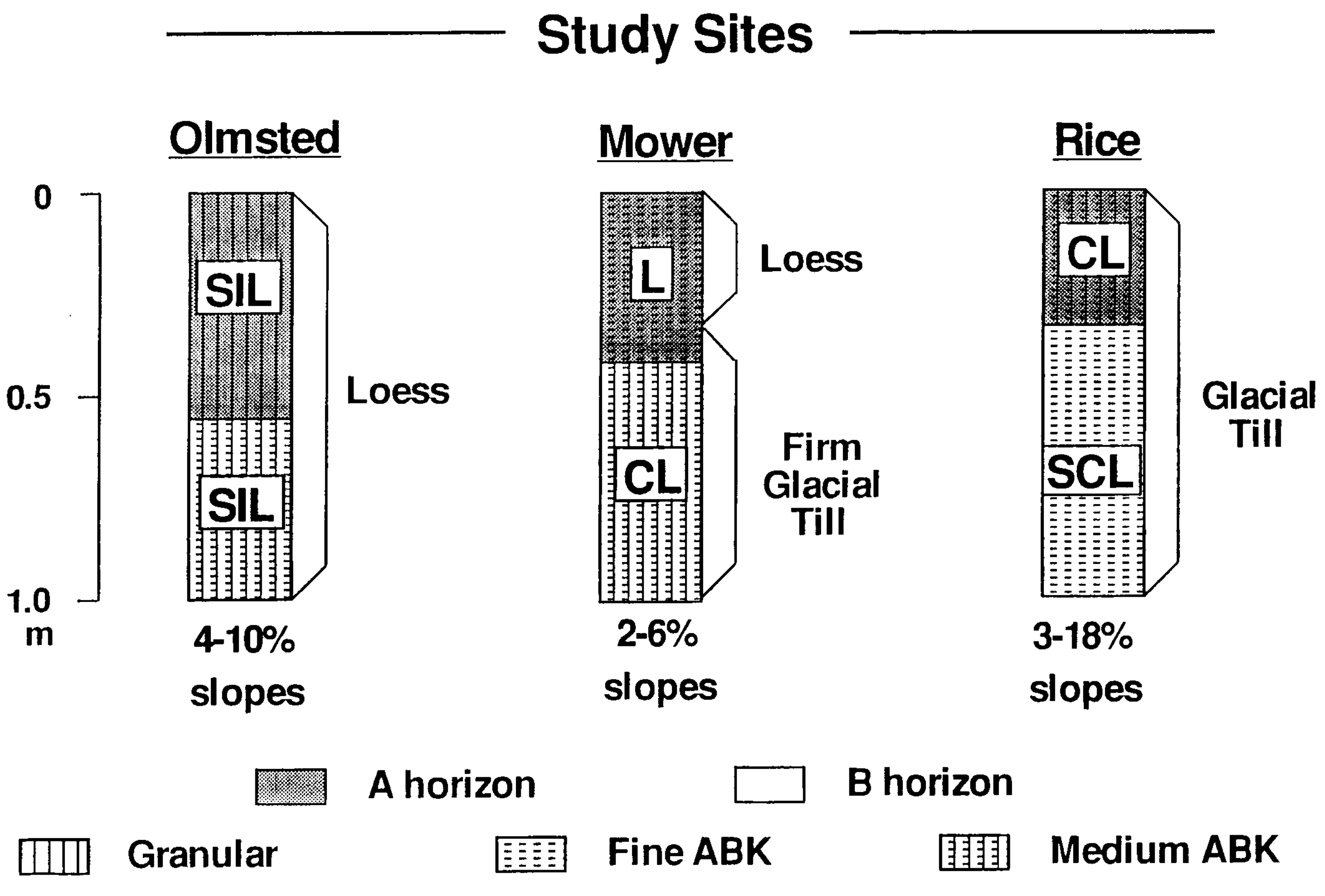

Figure 1. Generalized soil profiles, parent material, and slopes for soils at each study site.

is occurring in the affected area, i.e., removal of the organic rich epipedon.

Ephemeral channel-topographic parameter relationships. Two associations were consistently significant for all landscapes. The first, channel cross-sectional area, a measure of ephemeral erosion severity, was positively correlated to planform curvature (i.e., as planform curvature became more concave, channel area increased). The second, occurrence of deposition, was negatively correlated with slope. In addition, distance to channel was negatively correlated with planform curvature for both Olmsted ($P<0.07$) and Rice ($P<0.01$) sites.

To examine the relationship between erosion severity and topographic parameters, a stepwise regression analysis was conducted with channel area as the dependent variable and topographic attributes as independent variables. Between 18 and 22 extra points were randomly selected from portions of the watershed not previously sampled, and included in this analysis. Since these points were outside the affected areas, a channel area value of zero was assigned to each point. Model parameters selected for each site were different. Planform curvature was included as one of two parameters in all models. The second parameter for Olmsted was ABS (unit area•slope); the second for Rice was LNAS, Ln(unit area/slope); and the other parameter for Mower was CTI (upstream contributing area•slope•planform curvature). Regression (R^2) values and significance of model fit were 0.27 ($P=0.0001$) for Mower, 0.39 ($P=0.0001$) for Olmsted, and 0.42 ($P=0.0013$) for Rice. Several factors may have contributed to this low explanation of variance, i.e., other influential topographic parameters may need to be considered; additional factors such as soil strength, soil hydraulic conductivity, and runoff need to be incorporated into the model; a larger number of watershed samples may be needed to identify subtle relationships with topographic attributes; and DEM grid resolution [3 m (10 ft)] may not have been sufficient to accurately compute parameter values in all cases.

Burt and Butcher *(3)* found that planform curvature was a good predictor of saturated areas in watersheds. Ephemeral gullies would be most likely to form in such areas because critical shear stress of saturated soils is reduced, and convergence increases the probability that concentrated flow will develop on

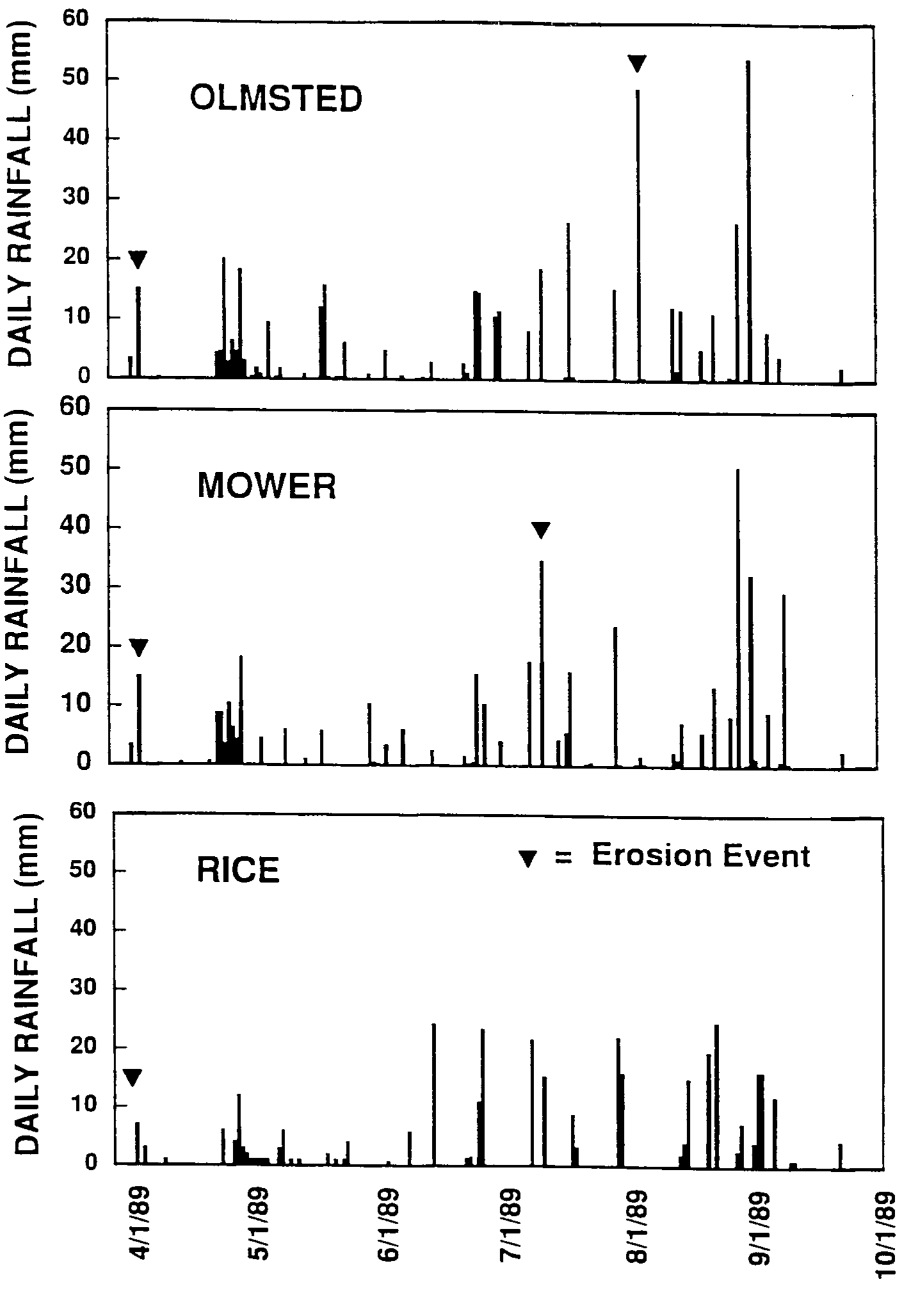

Figure 2. Daily precipitation and associated ephemeral erosion events at each site.

the surface *(19)*. The importance of ABS in the Olmsted regression most likely is a reflection of this factor's influence on sediment transport capacity of surface flow processes *(11)*. Moore *(10)*, O'Loughlin *(13)*, and Beven and Kirkby *(2)* found LNAS to be the best predictor of soil water content and surface saturation. The combination of LNAS with planform curvature in the Rice regression leads us to believe that saturation may play a relatively greater role in development of ephemeral gullies at this site. The majority of erosion at all sites occurred in early spring, while soil frost was present at some depth in the profile. Permeability of frozen soil is very low. Water perched above the frozen layer soon saturates the soil and induces significant subsurface flow. Thorne et al. *(19)* combined planform curvature in a product (CTI) that also included upstream contributing area and slope; the latter two providing an index of stream power. The presence of both planform curvature and CTI in the Mower regression indicates that interaction effects between upstream area, planform curvature, and slope, do not alone explain severity of ephemeral gully development.

The relationship between occurrence

of ephemeral gullies and topographic parameters was examined by utilizing the "distance from point to channel center" parameter as the dependent variable in regression models for each site. Additional watershed points selected for the channel area regression were also included in this analysis. Distance to channel for these points was estimated from DEM contour maps. The coefficient of multiple determination (R^2) and significance of model fit for the three models ranged from 0.28 ($P=0.0001$) for Rice, 0.51 ($P=0.0001$) for Olmsted, and 0.80 ($P=0.0001$) for Mower. Again, the models employed different parameters. Planform curvature, however, was common to all models and accounted for a dominant portion of explained variation at each site. Variation in channel occurrence at Olmsted was best explained using planform curvature, slope, and a combined index—profile curvature• slope (PSLP). Proximity to a channel increases as planform curvature becomes more concave and when slope decreases. PSLP has not been employed in previous research. Its use in this regression implies that when profile curvature becomes more concave and slope becomes less steep, the proximity to a channel is increased. Zaslavsky and Sinai *(21)* reported that profile curvature was of primary importance in determining the distribution of soil water content. We believe PSLP identifies areas where concavity encourages accumulation of soil water and low slope hinders subsurface lateral drainage. Channels tend to form in these areas where infiltration is reduced and surface flow down slope is sustained. Gully occurrence at Rice was most closely related to planform curvature and the combined indices LNAS and CTI. For Mower, much of the variation in proximity to channels was explained by planform curvature, slope, and combined indices—LNAS, ABS, and PSLP.

Soil properties of affected/nonaffected areas. Table 3 presents mean soil properties of affected and nonaffected areas for each site. Of 72 affected versus nonaffected comparisons examined, only nine pairs were significantly different ($P<0.05$). These are included in Table 3. Differences were observed in each reach but only one of the nine occurred in the upper channel position. Clearly, ephemeral gully erosion has its greatest impact on local soil properties at mid- and lower-channel positions. Soil properties most influenced were A horizon thickness and percent organic carbon, bulk density, and percent sand at 0.05-0.15 m (.2-.5 ft) depth. In general, percent organic carbon at 0.05-0.15 m depth in affected areas was 12 percent less than in nonaffected areas in lower channel positions. At mid-channel positions, the most systematic difference observed was in sand content of either 0.05-0.15 or 0.18-0.35 m (.6-1 ft) layers; affected areas had approximately 30 percent greater sand than nonaffected areas in one of these layers.

A lack of overall relationships suggests that each site (landscape) responded differently to ephemeral erosion processes. For example, in some landscapes, ephemeral gullies do not recur in precisely the same position in the swale each year. Instead, they may be initiated at various positions in the swale, depending on microtopographic variation in furrow configuration, swale planform curvature, or random weakness in tillage ridges that cross the swale and dam water. Channel wandering was observed at the Olmsted site; Figure 3 depicts early and late season ephemeral gully patterns that significantly diverge from one another. At the sampling scale used, the random formation of channels and subsequent filling would tend to minimize soil differences observed between affected/nonaffected locations. We believe this may explain why few differences were noted between affected and nonaffected areas at Olmsted (Table 3).

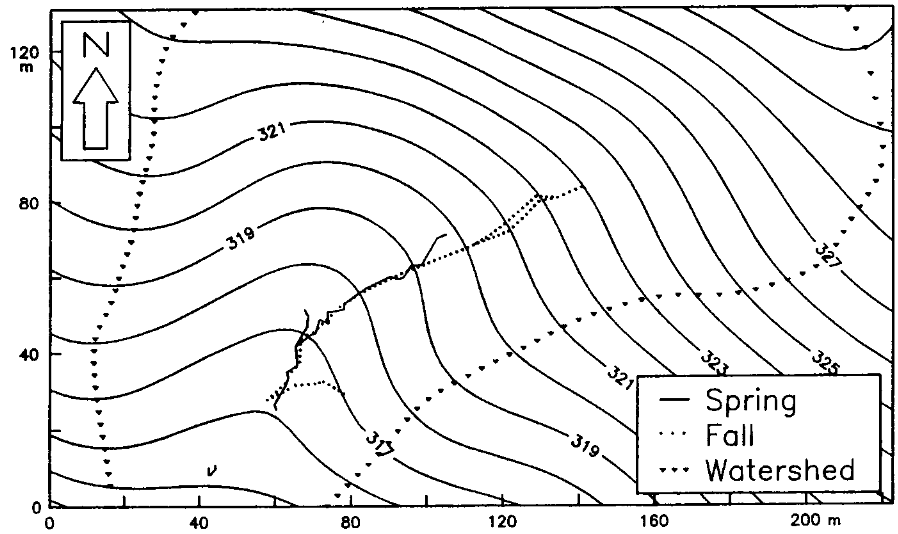

Figure 3. Olmsted ephemeral gully pattern, spring and fall, 1989 (units in meters.

Conclusions

Soil voidage associated with ephemeral erosion during dryer than normal seasons was one tenth that observed in wetter years. However, comparable storm events resulted in similar soil losses irrespective of season. The greatest impact of ephemeral erosion was observed at middle and lower reaches of the gully channel. A simple model describing 1) at upper gully positions, the removal of A horizon soil and tillage induced mixing with the B horizon, and 2) deposition of this sediment at lower gully positions, did not fully explain observed soil property relationships. The influence of ephemeral erosion on soil property patterns varied between sites as a function of relative 1) contributions from rill and interrill processes, 2) proclivity for channel drifting, and 3) occurrence of depositional sorting in channels. The lack of a consistent pattern of topography/erosion correlations between sites suggests that hydrologic processes occurring in different watersheds are significantly different. Our results suggest that one, two, or even three topographic parameters may not adequately describe ephemeral erosion hazards in various landscapes. Also, topographic parameters alone are not adequate to predict effects of ephemeral erosion on soil property patterns at a given site.

REFERENCES CITED

1. Aveyard, J., G.J. Hamilton, I.J. Packer, and P.J. Barker. 1983. *Soil conservation in cropping systems in southern New South Wales.* J. Soil Cons. New South Wales 39: 113-120.
2. Beven, K. and M.J. Kirkby. 1979. *A physically based variable contributing area model of basin hydrology.* Hydrol. Sci. Bull. 24: 43-69.
3. Burt, T.P. and D.P. Butcher. 1985. *Topographic controls of soil moisture distribution.* J. Soil Science 36: 469-486.
4. Dalsgaard, K., E. Baastrap, and B.T.

Bunting. 1981. *The influence of topography on the development of alfisols on calcareous clayey till in Denmark*. Catena 8: 111-136.
5. Foster, G.R. 1982. *Channel erosion within farm fields*. Preprint 82-007. American Society of Civil Engineers, New York.
6. Foster, G.R. 1986. *Understanding ephemeral gully erosion*. pp.90-128. In C. Carlson (ed.) *Soil conservation: Assessing the national resources inventory, Vol. 2*. National Academy Press, Washington D.C.
7. Grissinger, E.H. and J.B. Murphey. 1989. *Ephemeral gully erosion in the loess uplands, Gordwin Creek Watershed. Northern Mississippi, USA*. In International Research and Training Center on Erosion and Sedimentation (ed.) *Proceedings of the Fourth International Symposium on River Sedimentation, Beijing, China*. June 5-9, 1989. China Ocean Press, Beijing.
8. Hanna, A.W., P.W. Harlan, and D.T. Lewis. 1983. *Effect of slope on water balance under center-pivot irrigation*. Soil Sci. Soc. Am. J. 47: 760-764.
9. Hutchinson, M.F. 1984. *A summary of some surface fitting and contouring programs for noisy data*. Consulting Rep. No. ACT84/6, CSIRO Div. Water and Land Res.
10. Moore, I.D., E.M. O'Loughlin, and G.J. Burch. 1988b. *A contour-based topographic model for hydrological and ecological applications*. Earth Surface Proc. and Landforms 13: 305-320.
11. Moore, I.D., G.I. Burch, and D.H. MacKenzie. 1988a. *Topographic effects on the distribution of surface soil water and the location of ephemeral gullies*. Trans. ASAE 31: 1098-1107.
12. Mueller, R.G. 1982. *Soil genesis as influenced by three-dimensional landsurface form in two low-order drainage basins in the Flint Hills of Kansas*. Ph.D. diss. University of Kansas, Lawrence. (Diss. Abstr. DA8301737).
13. O'Loughlin, E.M. 1981. *Saturation regions in catchments and their relations to soil and topographic properties*. J. Hydrol. 53: 229-246.
14. Panuska, J.C. and I.D. Moore. 1991. *Water quality modeling: Terrain analysis and the agricultural non-point source pollution (AGNPS) model*. Tech. Rpt. No. 02/89. Water Resources Center, Univ. Minnesota, St. Paul, March 1991.
15. Pierson, F.B., and D.J. Mulla. 1990. *Aggregate stability in the Palouse region of Washington: Effect of landscape position*. Soil Sci. Soc. Am. J. 54: 1407-1412.
16. SAS Institute Inc. 1988. *SAS/STAT User's Guide, Release 6.03 edition*. SAS Institute Inc., Cary, NC.
17. Spomer, R.G. and A.T. Hjelmfelt Jr. 1986. *Concentrated flow erosion on conventional and conservation tilled watersheds*. Trans. ASAE 29: 124-128.
18. Thomas, A.W. and R. Welch. 1988. *Measurement of ephemeral gully erosion*. Trans. ASAE 31: 1723-1728.
19. Thorne, C.R., L.W. Zevenbergen, E.H. Grissinger, and J.B. Murphey. 1986. *Ephemeral gullies as sources of sediment*. pp.152-161. In *Proceedings of the Fourth Federal Interagency Sedimentation Conference*, Mar 24-27, 1986, Las Vegas, NV.
20. U.S. Department of Commerce National Oceanic and Atmospheric Administration, Environmental Data Service. 1986-9. *Climatological data annual summary, Minnesota, Vol. 95, No. 13*. National Climatic Data Center, Ashville, NC.
21. Zaslavsky, D. and G. Sinai. 1981. *Surface hydrology*. J. Hydraulics Div., ASCE 07: 1-64. ❑